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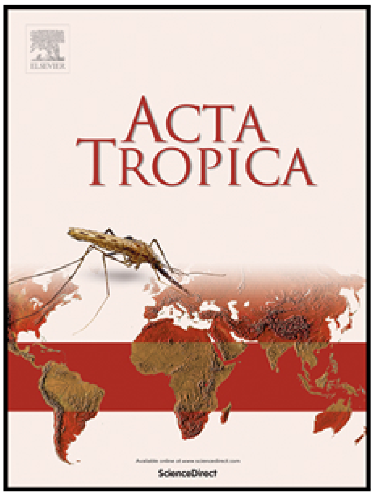

Modeling and updating the occurrence of Aedes aegypti in its southern limit of distribution in South America

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Highlights:

- *Aedes aegypti* was reported in 11 new cities of La Pampa province.
- Minimum temperature, precipitation and interactions between maximum temperature and precipitation explains the *Aedes aegypti* occurrence.
- Precipitation would be the most important factor for its occurrence.

Title: Modeling and updating the occurrence of *Aedes aegypti* in its southern limit of distribution in South America

Running Title: Occurrence of *Ae. aegypti* in South America

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Abstract

Aedes aegypti is the main vector of arboviruses in the world. This mosquito species is distributed from tropical to temperate regions. In Argentina, it has been reported in 20 out of 23 provinces and reaches its southernmost distribution in the world. Its distribution and persistence are affected by meteorological, demographic and environmental factors, such as temperature, precipitation, and population. The aim of this study was to update and model the occurrence of *Aedes aegypti* in its southern limit of distribution in Argentina. To this end, a total of 37 sites were inspected in La Pampa and Río Negro provinces. Generalized Linear Models were used to explain the occurrence of *Aedes aegypti* based on meteorological, environmental and demographic variables. *Aedes aegypti* was found in 11 cities of La Pampa province where it had not been previously reported, but was not found in any of the cities evaluated in Río Negro province. The averaged model explaining the occurrence of *Aedes aegypti* included the minimum temperature, precipitation and interactions between maximum temperature and precipitation as explanatory variables. Although precipitation was statistically significant, other factors such as minimum temperature are also important in modeling the occurrence of *Aedes aegypti* in its southernmost distribution limit.

Key words: model, temperate region, South America, *Aedes aegypti*, meteorological, demographic and environmental variables

1. Introduction

Aedes aegypti (Diptera: Culicidae) is a mosquito species involved in the transmission of multiple arboviruses, including dengue, Zika, yellow fever and chikungunya (Gubler, 2010). In the Americas, dengue has a high incidence in the population, with around 2,89 million cases in 2016, 3,1 cases in 2019, and around 3 million cases in 2022 (PAHO, 2023). In Argentina, between September 2022 and April 2023, there were 41,257 cases of dengue, almost 92% of which corresponded to autochthonous vectorial transmission, and 27 of which were fatal. These are the highest numbers of dengue cases ever recorded in the country (MSA, 2023). Since this incidence is influenced by the close relationship between humans and vector mosquitoes, it is imperative to gain insights into the distribution and abundance of this important mosquito species (Powel & Tabanick, 2018).

Aedes aegypti, which is native to tropical regions of Africa, was introduced into the Americas between the XV and XVII centuries, possibly through water containers transported in ships (Powell, 2018). In the Americas, after the eradication campaign that took place between 1930 and 1960, several countries, including Argentina, certified the elimination of *Ae. aegypti* from their territories. Later, the discontinuity in the surveillance and control program led to a gradual reinfestation of the vector in old and new places (Gubler & Clark, 1995). In Argentina, *Ae. aegypti* was detected again in the northeastern provinces of Formosa and Misiones in 1987 (Curto et al., 2002) and, subsequently, it also spread beyond its historical southern limit (Diez et al., 2014; Zanotti et al., 2015; Rubio et al., 2020). Nowadays, *Ae. aegypti* is distributed from the south of the USA to the center of Argentina, encompassing tropical, subtropical, and temperate climates. The presence of *Ae. aegypti* in Argentina has been documented in 20 out of 23 provinces, with La Pampa, Buenos Aires, Neuquén and Río Negro provinces constituting its southern limit of distribution (Stein et al., 2016; Rubio et al., 2020). In La Pampa province, *Ae. aegypti* was first reported in Santa Rosa city (the capital of the province) in 1992 (Carpintero & Leguizamon, 2004) and later reported in other nine cities (Curto et al., 2002; Diez et al., 2011; 2014).

According to previous studies, meteorological variables such as temperature and rainfall, as well as urbanization and vegetation, play a key role in the distribution and abundance of this mosquito (Estallo et al., 2018; Carbajo et al., 2019; Sánchez-Díaz et al., 2021). Temperature affects the development, growth rate and metabolic activity of mosquitoes (e.g., flying, blood-feeding, among others) (Eisen et al., 2014; Reinhold et al., 2018). Under lower temperature, the activity of *Ae. aegypti* decreases, being 12 °C the limit where it can develop (De Majo et al., 2019). In contrast, at higher temperatures, the activity of the mosquito increases, although extreme temperatures above 35°C also limit its flying and feeding activities (Reinhold et al., 2018). An increase in the mean temperature also reduces the gonotrophic cycle (Carrington et al., 2013). On the other hand, precipitation also affects the life cycle dynamics of *Ae. aegypti* because it promotes the filling of containers for the development of immature stages (Koenraadt & Harrington, 2008). Both high rainfall (Fischer et al., 2017) and consecutive days of rain may increase the population dynamics of *Ae. aegypti*. Nevertheless, rainfall for 5 consecutive days or more no longer increases the abundance of this mosquito (Tokachil & Yusoff, 2018), due to the overflow and washing of the containers and therefore loss of larvae and pupae (Tokachil & Yusoff, 2018). Due to the close relationship between this mosquito species and human settlements, demographic variables such as increases in urbanization and in the human population density are important predictors for the presence of *Ae. aegypti* (Christophers, 1960), because affect itsabundance, spatial distribution, dispersion and other patterns (e.g., oviposition) (Wilke et al., 2021).

Several models have been proposed to explain the occurrence and distribution of *Ae. aegypti*. These models have been assessed using climate and socio-environmental variables, but these large-scale models are less accurate in extreme regions (Kraemer et al., 2015). Some models have been carried out in the temperate region (Estallo et al., 2018; Sánchez-Díaz et al., 2021; Benitez et al., 2021) but only one study has modeled the distribution of *Ae. aegypti* in the southern limit of South America (Carbajo et al., 2019). So, the aim of this study was to update and model the occurrence of *Ae. aegypti* in its southern limit of distribution in Argentina.

2. Material and methods

2.1 *Study area*

La Pampa and Río Negro provinces are located in the temperate region of Argentina, in the northern limit of Argentine Patagonia. These provinces are separated by the Colorado River and the climatic conditions and vegetation of southern La Pampa and northern Río Negro provinces are similar.

La Pampa is located in the central region of Argentina and has a surface area of 143,440 km² and a population of 349,299 inhabitants (INDEC, 2010). It has a strong climatic seasonality, with most precipitation occurring between spring and early fall. The annual mean temperature is between 14 and 16 °C, with the mean of the warmest month (January) being 24 °C and the mean of the coldest month (July) being 8 °C. The average precipitation ranges between 700 and 200 mm annually (Casagrande, 1980). Río Negro province is located south of La Pampa and has a surface area of 203,013 km² and a population of 757,052 inhabitants (INDEC, 2010). In particular, the area known as Alto Valle del Río Negro has an arid/semiarid climate with low rainfall throughout the year, mainly concentrated in summer and autumn. The annual mean temperature is between 15.3 ± 1.2 and 15.8 °C for the areas of Valle Medio and Río Colorado, respectively. The coldest period is between June and August, whereas the warmest period is between December and February. The mean precipitation ranges between 300 and 459 mm annually for the areas of Valle Medio and Río Colorado, respectively (Rodríguez & Muñoz, 2020). This region is characterized by fruit production activities (Rodríguez, 2013).

2.2 *Sampling sites and collection of Aedes aegypti*

A total of 29 cities were sampled in La Pampa province and 8 in Río Negro. During the summer of 2020 and 2021, the potential breeding sites (tire repair stores, cemeteries, garbage dumps, etc.) in each city were identified and screened for the presence of immature stages of *Ae. aegypti*, which were collected with a dipper and pipette for later identification at the laboratory. Adult mosquitoes were collected with hand aspirators. The sampling was conducted during the summer season, as it represents the peak period of mosquito activity, increasing the likelihood of finding the target species. Most of the containers at each site were inspected. In the case of cemeteries, due to their small sizes, all vases and containers were inspected. Cities with presence of *Ae. aegypti* were reported as positive, whereas those with absence of *Ae. aegypti* were considered negative (Table 1).

***2.3** Meteorological, environmental and demographic variables*

Predictor variables were chosen based on bibliography and prior knowledge of factors affecting mosquitoes. These included meteorological, environmental and demographic variables (see Table S1). Meteorological variables were obtained from meteorological stations (= data loggers) located in the different cities sampled. In La Pampa province, these data loggers were placed by the Ministerio de Producción de la Provincia de La Pampa (https://lapampa.redesclimaticas.com/accounts/), whereas, in Río Negro province, they were placed by the Instituto Nacional de Tecnología Agropecuaria (INTA) (https://sipan.inta.gob.ar/agrometeorologia/met/42/clima.htm). The meteorological variables considered were minimum, maximum and mean temperature, accumulated precipitation and mean humidity in each city for the period 2020-2021. Environmental variables for each city (mean, maximum, minimum values of built-up pixels and proportion of built-up pixels/total pixels of the Normalized Difference Built-up Index -NDBI-) were calculated from satellite images of the Sentinel 2-A satellite for the summer season of the two years sampled. These images were selected according to the availability of images on the website and the absence of clouds over the area of interest. The B8A (865 nm) and B12 (2190 nm) bands with 20 m spatial resolution (https://scihub.copernicus.eu/) were used to perform the calculations. All images were processed and analyzed with the QGis software (version 3.16.10). The demographic variables considered were population (number of inhabitants) and distance to national or provincial roads. Total population values for each city were obtained from the National Institute of Statistics and Censuses of Argentina (INDEC, 2010). The distance to national or provincial roads was calculated from the centroid of each city until the nearest road, using Google Earth Pro.

2.4 *Data analysis*

The response variable was the occurrence of *Ae. aegypti*, i.e. the presence-absence of the mosquito in each city. The presence-absence found in this study was analyzed together with that found in eight cities of La Pampa province where the presence of *Ae. aegypti* had been previously reported (Diez et al., 2014). The predictor variables included in the models are shown in Table 2. A multicollinearity analysis between predictor variables was performed using Pearson's correlation coefficients ($r < 0.6$). Predictor variables were centered and standardized before being included in the Generalized Linear Model (GLM) with binomial error distribution and *logit* link.

Different models were built to explain the occurrence of *Ae. aegypti*, using meteorological, environmental and demographic variables with their biological justification (Table 2). The models were evaluated using the Akaike Information Criterion corrected for small sample sizes (AICc) (Burnham & Anderson, 2004). Cumulative Akaike weights (ω) were used to produce a 'confidence set' of models that are the most realistic probability of being the best-approximating model, rejecting the models in which ω exceeds 0.95 (Burnham & Anderson, 2004). Parameter estimates from the average model were obtained using the ω AICc values from a subset of candidate models. To assess the significance of parameter estimates, the 95% confidence interval (CI) was calculated using unconditional variances. A variable was assumed to be significantly associated with the presence of *Ae. aegypti* if its CI excluded zero. The estimated log-odds were divided by four to obtain the probabilities of *Ae. aegypti* presence corresponding to a unit difference in the explanatory variable. Overdispersion, model assumptions goodness of fit and spatial autocorrelation were checked. Finally, the ability of the model to predict *Ae. aegypti* occurrence was evaluated using the area under the receiver operating characteristic (ROC) curve (AUC). The AUC ranges between 0 and 1, with AUC values closer to 1 indicating a better model. We also evaluated the Brie Score value, whose values range between 0 and 1, with values near 0 being the better predictions of the model. Statistical analyses were performed in R version 3.6.3 with RStudio 1.4.1717 interface (RStudio Team, 2021).

3. Results

A total of 29 cities in La Pampa and 8 cities in Río Negro provinces were screened for the presence of *Ae. aegypti* during the summer of 2020 and 2021. In La Pampa province, the mosquito was detected in 15 cities, four of which had already reported the presence of *Ae. aegypti*. In contrast, none of the cities screened in Río Negro province was positive for *Ae. aegypti* (Figure 1).

The mean temperature, mean humidity, and minimum and maximum value of the NDBI were excluded from the multicollinearity analysis. The averaged model explaining the occurrence of *Ae. aegypti* included the minimum temperature, precipitation and interactions between maximum temperature and precipitation as explanatory variables (cumulative weight = 86% and ΔAICc<3, Table 3); the minimum temperature and interaction between maximum temperature and precipitation were not statistically significant because the CI included zero (Table 4).

The average estimate of the precipitation, minimum temperature and interaction between maximum temperature and precipitation values were 2.52, -0.98 and 1.21, respectively (Table 4), which means that, for each unit of increase in the precipitation standard deviation, the probability of finding *Ae. aegypti* increases by 63% (Figure 2). Although the minimum temperature was not statistically significant, a negative trend was observed between the occurrence of *Ae. aegypti* and the minimum temperature (Figure 2). The interaction between maximum temperature and precipitation was not statistically significant; however, regardless of the temperature, the probability of finding *Ae. aegypti* increased with precipitation (Figure 3). The averaged model obtained an AUC value of 0.9 and a Brie Score value of 0.123 .

4. Discussion

Aedes aegypti is a tropical mosquito species that has spread to temperate regions, including Argentina (Eisen et al., 2014). It was certified as eradicated in 1963 but reintroduced in 1975 in Brazil, causing re-infestations in countries of the Southern Cone (Vezzani & Carbajo, 2008). In Argentina, *Ae. aegypti* has been documented in 20 of the 23 provinces, showing that its distribution has enlarged both westwards and southwards compared to its historical range. Recent studies have confirmed its successful establishment in temperate regions such as Buenos Aires and La Pampa provinces (De Majo et al., 2019; Obholz et al., 2022) and have shown that its adaptation to these challenging environmental conditions could be related to photoperiod-induced embryonic dormancy (Fischer et al., 2019).

In the present study, we inspected different cities in search of the presence of *Ae. aegypti* and developed several models to explain its occurrence in relation to meteorological, environmental and demographic variables in its southern limit of distribution. To this end, we documented new reports of *Ae. aegypti* in La Pampa province, expanding the knowledge of its western distribution limit, being the city of Santa Isabel the westernmost record in the province so far (Fig. 1). Although *Ae. aegypti* had already been reported in the northeast of La Pampa province, in the present study its presence was found in Embajador Martini city, in which it was previously absent (Diez et al., 2014). In the southeast, its distribution was maintained in the same latitude, as previously detected (Diez et al., 2014), being the cities of General Acha and Alpachiri, the southernmost records in the province (Fig. 1).

Some of the cities inspected in Río Negro and La Pampa provinces turned out to be negative, which aligns with the predictions of the model of Carbajo et al. (2019). Although the model predicted the probability of finding *Ae. aegypti* in several cities such as La Adela in La Pampa province and Río Colorado in Río Negro province, we did not find the mosquito in these localities, which is consistent with the findings of Rubio et al. (2020). Recently, *Ae. aegypti* has been reported in San Antonio Oeste (Río Negro province), probably as a result of eggs laid by gravid females transported by travel or commercial transport (Rubio et al., 2020). However, in the present study, we did not find the mosquito in any of the localities inspected in Río Negro province.

The distribution and persistence of *Ae. aegypti* are influenced by several factors, including precipitation, temperature, urbanization, and the vegetation index (Dickens et al., 2018). Nevertheless, some of them play a key role in the delimitation of its distribution. In this study, the averaged model that explained the occurrence of *Ae. aegypti* included the minimum temperature, precipitation and interaction between maximum temperature and precipitation as explanatory variables.

Precipitation is one of the most important factors because it is essential for the availability of water in containers for the oviposition and development of immature stages of *Ae. aegypti* (Micieli & Campos, 2003). However, results in this respect are contradictory. Some previous studies in Córdoba city (temperate region of Argentina) have shown a positive relationship between precipitation and the oviposition activity of this mosquito (Sánchez-Díaz et al., 2021), whereas others have found a negative relationship (Benitez et al., 2021). In the state of Florida, USA, Yang et al. (2021) observed a positive association between increased precipitation and the abundance of *Ae. aegypti*, but no association regarding the probability of its presence.. Similar results were found by Carbajo et al. (2019), who found no relationship between precipitation and the occurrence of *Ae. aegypti*. In contrast, in this study, we found a positive relationship between precipitation and *Ae. aegypti* occurrence. Sites where the mosquito was found correspond to areas where precipitations are high (> 750 mm annually), with the exception of Santa Isabel city (<300 mm annually). As already mentioned, Precipitation plays an important role in the presence, activity and development of several mosquito species, particularly in those that breed in natural sites (i.e., *Culex* spp., *Psorophora* spp., *Mansonia* spp.). Since *Ae. aegypti* is well adapted to artificial containers, this relationship may be affected by human activities. In the present study, one of the cities in which *Ae. aegypti* was found was Santa Isabel city, where precipitation is below 300 mm annually, but where tire repair store owners or workers usually pour water onto the tires (i.e. larval habitats) for them not to become damaged due to sun exposure.

Several works have documented the effect between the temperature and the distribution of *Ae. aegypti* at regional (Estallo et al., 2018; Carbajo et al., 2019) and global scale (Brady et al., 2014; Kraemer et al., 2015). In certain temperate regions, at the winter isotherm of 10°C, this mosquito seems to remain in the egg stage throughout the winter season until conditions become more favorable (Christophers, 1960). It has been extensively studied that the activity of mosquitoes decreases with decreasing temperatures (Cristophers, 1960; Carrington et al., 2013; De Majo et al., 2019). In *Ae. aegypti*, the minimum temperatures required for larval development can vary depending on the conditions, but temperatures below 12°C drastically decrease its survival and can be lethal (Carrington et al., 2013; De Majo et al., 2019). In the temperate region of Argentina, some studies have shown that the minimum temperature affects both the activity and oviposition dynamics of *Ae. aegypti* (Benitez et al., 2021), whereas other studies have found a negative association between minimum temperature and the occurrence of *Ae. aegypti* (Eisen et al., 2014), and that temperatures below 14ºC would not be favorable for its establishment (Carbajo et al., 2019). In this study, although the association between minimum temperature and the occurrence of *Ae. aegypti* was not significant, a trend of decreasing *Ae. aegypti* occurrence was observed when the minimum temperature decreases. Although this finding is contradictory to that biologically expected, we believe that this trend may be due to the fact that the models reflect the presence of the mosquito but not its development. This trend can also indicate the expansion of *Ae. aegypti* distribution to colder areas. Recent studies on the resistance of *Ae. aegypti* eggs to winter conditions (De Majo et al., 2017; Obholz et al., 2022) and on the ability of a short-day photoperiod to inhibit egg hatching (Fischer et al., 2019) could indicate a possible adaptation of this mosquito species to temperate zones. However, since this was not statistically significant, further studies are needed for a more in-depth analysis. In future studies, it would be interesting to include the daily range of temperature fluctuations, as this could be related to the presence of this mosquito species.

High temperature associated with high precipitation can also affect the life cycle of mosquitoes, favoring their development and survival (De Mello et al., 2022). Therefore, in the present study, we included the interaction between maximum temperature and precipitation because this could affect the suitability of containers. As mentioned earlier, precipitation affects the water levels in the containers, but high temperatures can lead the water level to decrease or dry out completely and therefore increase the mortality of immature stages (larvae and pupae) (Alto & Juliano, 2001). In the present study, we found no significant interaction between both variables but, regardless of the temperature, an accumulated precipitation of approximately 800 mm was necessary to find *Ae. aegypti*. This is important because this variable maintained the suitability of the containers for the development of the immature stages, favoring *Ae. aegypti* establishment.

As mentioned, some studies have reported that another important factor in predicting the presence and abundance of *Ae. aegypti* is the human population (Estallo et al., 2018; Carbajo et al., 2019; Yang et al., 2021). However, in this study, this factor did not have much weight. This may be due to the fact that the cities sampled in La Pampa and Río Negro provinces have low human population and low degree of urbanization. However, these are key factors given the importance of humans in providing a blood meal source (for the development of the eggs) and breeding sites (artificial containers), and in the mosquito dispersal mechanism. Therefore, in future studies, it would be necessary to include other factors associated with human activity that are related to the activity of the mosquito.

Different containers documented as breeding sites for *Ae. aegypti* include flower vases, tires, and flasks, among others (Christophers, 1960). As in most *Aedes* species, the female has a preference for laying its eggs on moist surfaces inside a container (Hawley, 1988), and in places with previously stagnant water that are floodable (Clements, 1963). In addition, previous studies have shown that female *Aedes* mosquitoes prefer dark containers to lay their eggs (Tsunoda et al., 2020). In this study, tire repair stores were the most frequently positive sites for the presence of *Ae. aegypti*. Generally, tires accumulate a little amount of water and a lot of organic matter, which is why they could be preferentially chosen as an oviposition site. Also, the position and shape of tires and the difficulty in removing all the accumulated water inside tires make them a good breeding site. In comparison with that previously found in Buenos Aires province (Vezzani, 2007), we did not find *Ae. aegypti* presence in the cemeteries sampled. This could be due to the new policies of control and eradication of dengue vectors, which have prohibited leaving flower vases holding water in cemeteries and promote the use of plastic flowers in containers filled with soil.

Both the province of La Pampa and Río Negro have strong seasonality and are in the southernmost region of South America, where the climatic factors play a key role in the distribution of *Ae. aegypti*. The main factors that were found to explain the occurrence of *Ae. aegypti* in this southern limit of distribution are minimum temperature and the interaction between maximum temperature and precipitation. Our results increase the knowledge about the distribution of *Ae. aegypti* and the factors driving its southern limit of distribution. In addition, the knowledge of different breeding sites used by *Ae. aegypti* in different regions contributes to decision-making in the prevention, surveillance and control measures of this mosquito species. Given the ongoing expansion of *Ae. aegypti* and current global warming scenario, it is essential to have predictive tools on the presence and abundance of this important disease vector.

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CRediT authorship contribution statement

Gisella Obholz: Formal analysis, Investigation, Data curation, Visualization, Writing - original draft, Writing - review & editing. **Germán San Blas**: Supervision, Visualization, Writing - review & editing. **Ana Paula Mansilla**: Methodology, Writing - review & editing. **Adrián Diaz**: Conceptualization, Investigation, Methodology, Supervision, Funding acquisition, Project administration, Resources, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Tables

Table 1. *Aedes aegypti* occurrence in different inspected sites in different cities of La Pampa and Río Negro provinces, Argentina. The plus symbol indicates presence, the minus symbol indicates absence, and empty spaces denote the absence of data (neither bibliographic nor from our samples).

Latitude	Longitude	City	Province	Reported presence	Inspected sites	Occurrence		
						Before 2020	2020	2021
-36.620922	-64.2912369	Santa Rosa	La Pampa	Carpintero and Leguizamón 2004, this study	5 tire repair stores and 1 cemetery	+		+
-35.0368673	-64.2465285	Realicó	La Pampa	Curto 2002	See cited reference	+		
-35.3871746	-64.2828108	Embajador Martini	La Pampa	Diez et al. 2014, this study	2 tire repair store and 1 household	-		+
-35.6635985	-63.754276	General Pico	La Pampa	Diez et al. 2011, this study	5 tire repair stores, 1 cemetery and 3 households	+		+
-35.0677025	-64.6839724	Rancul	La Pampa	Diez et al. 2011	See cited reference	+		
-35.9160568	-64.2956982	Eduardo Castex	La Pampa	Diez et al. 2014	See cited reference	+		
-37.3781867	-64.6043041	General Acha	La Pampa	Diez et al. 2014, this study	3 tire repair stores and 1 cemetery	+		+
-35.2350671	-63.5925316	Intendente Alvear	La Pampa	Diez et al. 2014	See cited reference	+		

-35.1466318	-64.5019205	Parera	La Pampa	Diez et al. 2014	See cited reference	+		
-35.6983232	-64.1331894	Trenel	La Pampa	Diez et al. 2014	See cited reference	+		
-36.2163499	-65.4372286	Victorica	La Pampa	this study	4 tire repair stores and 1 cemetery		+	
-36.2304306	-66.9391496	Santa Isabel	La Pampa	this study	4 tire repair stores and 1 household		+	
-38.9842432	-64.0891171	La Adela	La Pampa	Rubio et al., 2020, this study	2 tire repair stores and 1 cemetery	-	-	
-37.7711111	-67.7172222	25 de Mayo	La Pampa	this study	4 tire repair stores and 8 households		-	-
-37.9788459	-63.6036	General San Martín	La Pampa	this study	2 tire repair stores, park with tires, 2 households and shed with tires		-	-
-37.8963806	-63.8502359	Abramo	La Pampa	this study	1 tire repair store and 1 household		-	-
-36.2643346	-65.5115119	Telen	La Pampa	this study	2 tire repair stores		+	
-36.2036235	-65.1000102	Luan Toro	La Pampa	this study	3 tire repair stores and 1 cemetery		+	
-37.8794088	-67.7932024	Catriel	Río Negro	this study	3 tire repair stores, 1 garbage dump and 1 cemetery		-	
-38.6861	-68.1581	Sargento Vidal	Río Negro	this study	1 tire repair store and 1 garbage dump		-	
-38.8274421	-68.0660507	Cinco Saltos	Río Negro	this study	1 tire repair store and 1 cemetery		-	
-38.9278173	-67.9925103	Cipolletti	Río Negro	this study	6 tire repair stores and 1 cemetery		-	
-39.012981	-67.5956831	General Roca	Río Negro	this study	5 tire repair stores and 1 cemetery		-	
-39.1012244	-67.0881954	Villa Regina	Río Negro	this study	4 tire repair store and 1 cemetery		-	
-39.2946503	-65.6551733	Choele Choel	Río Negro	this study	3 tire repair store and 1 cemetery		-	
-38.990833	-64.095833	Rio Colorado	Río Negro	Rubio et al., 2020, this study	3 tire repair stores and 1 cemetery	-	-	

-37.9017927	-63.7428167	Bernasconi	La Pampa	this study	2 tire repair stores, 2 households and 1 garbage dump		-	-
-37.668177	-63.5374262	Guatraché	La Pampa	this study	3 tire repair stores, 1 cemetery and 2 households		-	-
-37.1369035	-63.6668172	Macachín	La Pampa	this study	4 tire repair stores, 1 cemetery		+	
-36.406679	-63.4233062	Catriló	La Pampa	this study	2 tire repair stores		+	
-36.856526	-63.6878078	Miguel Riglos	La Pampa	this study	2 tire repair stores		+	
-36.4698171	-63.6230267	Lonquimay	La Pampa	this study	2 tire repair stores		+	
-38.1463536	-65.9141064	Puelches	La Pampa	this study	4 tire repair stores and 3 households			-
-37.332049	-65.6516004	Chacharramendi	La Pampa	this study	2 tire repair stores			-
-38.1559042	-67.1481562	Casa de Piedra	La Pampa	this study	4 households			-
-37.5507182	-66.2265391	La Reforma	La Pampa	this study	1 tire store and 1 cemetery			-
-37.3770679	-63.7732461	Alpachiri	La Pampa	this study	2 tire repair stores and 2 households			+
-37.4614594	-63.5858131	General Manuel J Campos	La Pampa	this study	1 tire repair store, 1 workshop with tires and 1 households			-
-38.0854833	-63.4307367	Jacinto Arauz	La Pampa	this study	3 tire repair stores and 1 cemetery			-
-37.1493217	-64.0127343	Doblas	La Pampa	this study	1 household			+

Table 2. Models proposed to analyze the association between meteorological, demographic and environmental variables and the occurrence of *Aedes aegypti*.

Models	Description	Biological hypothesis
M0	Global model	Meteorological, demographic and environmental variables considered in this study explain the occurrence of *Aedes aegypti*.
M1	Null model	Meteorological, demographic and environmental variables considered in this study do not explain the occurrence of *Aedes aegypti*.
M2	Temp min + Temp max*Precipitation	Strong seasonality, i.e., low temperature in winter and high temperature in summer, determines mosquito survival. Low temperature limits egg survival. Also, the interaction between low precipitation and high temperature leads to the evaporation of the water of breeding sites.
M3	Temp max*Precipitation	Evaporation is important for the development of immature stages. Places where the maximum temperature is high will lead to a rapid evaporation of the water of breeding sites even if precipitation is high.
M4	Temp min + Precipitation	Egg survival is limited by the minimum temperature. In places where the minimum temperature is low, this variable may determine egg survival. Also, if these places have low rainfall, this will limit the development of immature stages.
M5	Precipitation	Places where the precipitation is abundant boost the accumulation of water in different containers and thus favor the development the immature stages.
M6	Log (Population) + MeanvalueNDBI	Places with greater human population and urbanization would increase the probabilities to find this mosquito.
M7	NDBIconst*Precipitation	A high degree of urbanization boosts the development of different breeding sites, which, together with abundant precipitation, favor the development of immature stages.
M8	Distance to national or provincial road	The passive dispersion of mosquitoes is favored by human and vehicular traffic from areas where the mosquito is present to areas where it is not.

Table 3. Models for the occurrence of *Aedes aegypti* based on the hypotheses generated ranked by their Akaike information criterion (AIC) scores.

Models	K	AIC	Delta_AIC	AICWt	Cum.Wt	R^2
Temp min + Precipitation	3	36.36	0.00	0.48	0.48	0.45
Precipitation	2	37.80	1.43	0.24	0.72	0.38
Temp min + Temp max*Precipitation	5	38.83	2.47	0.14	0.86	0.50
Temp max*Precipitation	4	39.25	2.89	0.11	0.97	0.44
NDBIconst*Precipitation	4	42.02	5.66	0.03	1.00	0.39
Distance to national and provincial roads	2	54.90	18.54	0.00	1.00	0.064
null	1	56.15	19.79	0.00	1.00	1.11e-16
logPopulation + MeanvalueNDBI	3	56.96	20.59	0.00	1.00	0.069

Table 4. Averaged model estimate, standard error (SE) and intervals of explanatory variables. Boldface indicates explanatory variables with 95% CIs excluding zero.

Explanatory variable	Parameter estimate ± SE	CI	
		Lower	Upper
Precipitation	**2.52± 0.82**	**0.93**	**4.12**
Minimum Temperature	-0.98 ± 0.56	-2.07	0.11
Maximum Temperature*Precipitation	1.21 ± 0.94	-0.63	3.05

Figure Legends

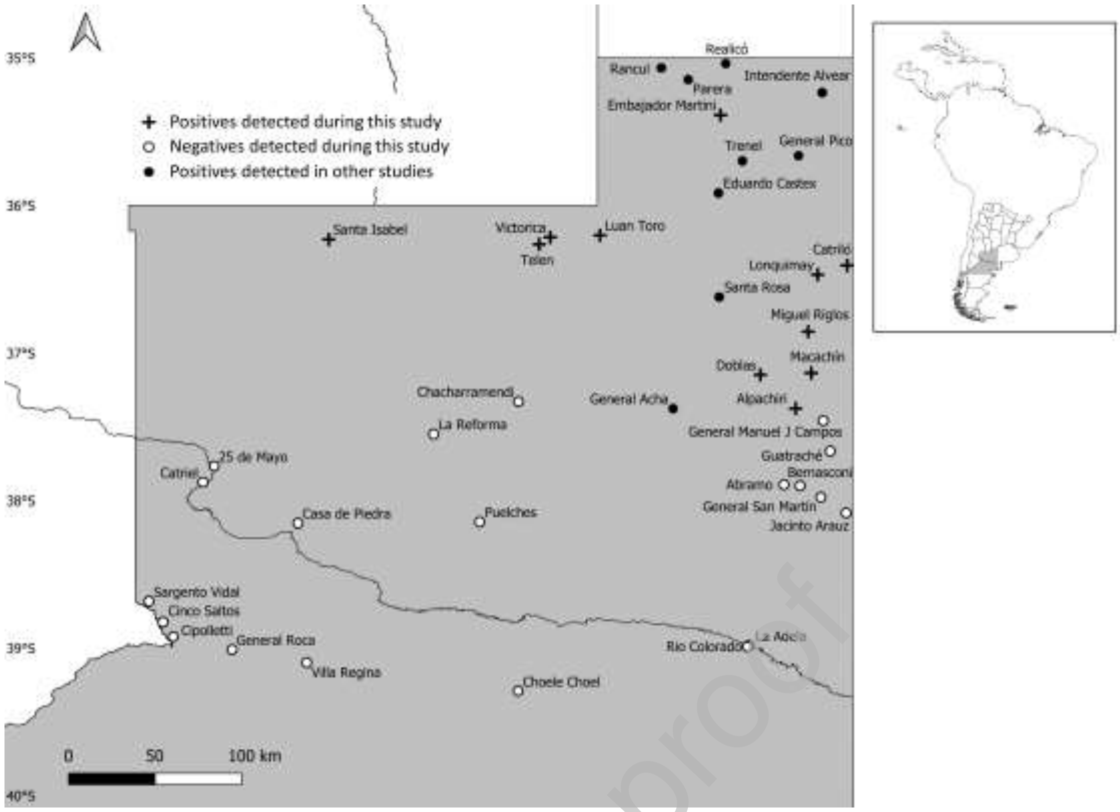
Figure 1. Map of *Aedes aegypti* occurrence in La Pampa and Río Negro provinces, Argentina (marked in gray), considering previous records of positive presence (Carpintero and Leguizamon, 2004; Curto, 2002; Diez et al., 2011, 2014) and the localities surveyed during this study.

Figure 2. Probability of *Aedes aegypti* presence in relation to accumulated precipitation and minimum temperature. Both explanatory variables are entered and standardized.

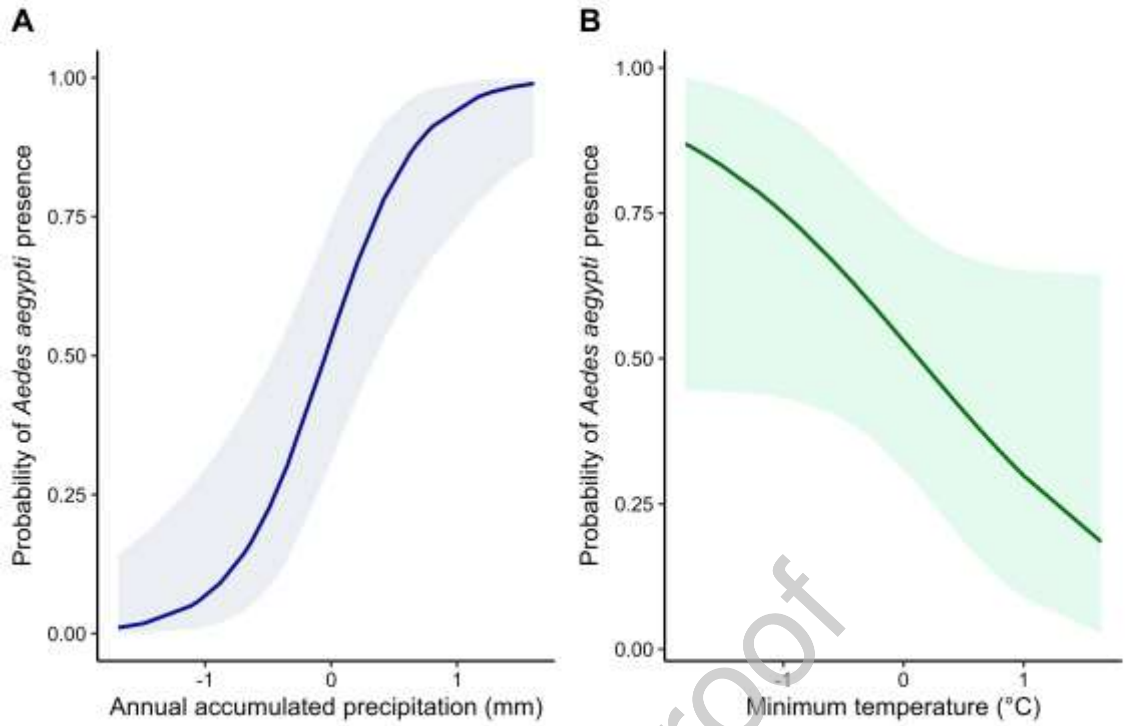
Figure 3. Probability of *Aedes aegypti* presence in relation to the interaction between maximum temperature and accumulated precipitation.

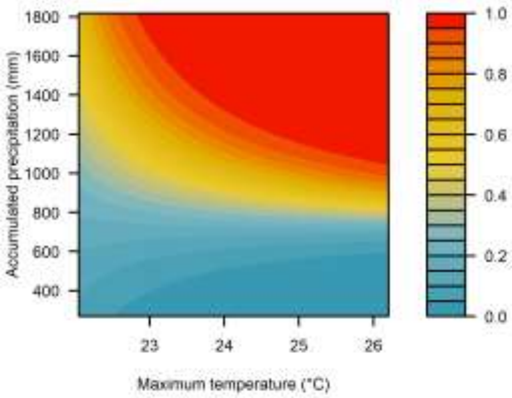
Appendix: Supplementary material

Table S1. Meteorological, environmental and demographic variables for the occurrence of *Aedes aegypti* in each city.



35°S
36°S
37°S
38°S
39°S
40°S
Positives detected during this study
Negatives detected during this study
Positives detected in other studies
Realicó
Rancul
Parera
Intendente Alvear
Embajador Martini
Trenel
General Pico
Eduardo Castex
Santa Isabel
Victorica
Telen
Luan Toro
Catriló
Lonquimay
Santa Rosa
Miguel Riglos
Doblas
Macachín
Chacharramendi
General Acha
Alpachiri
La Reforma
General Manuel J Campos
Guatraché
Bernasconi
Abramo
General San Martín
Jacinto Arauz
25 de Mayo
Catriel
Casa de Piedra
Puelches
Sargento Vidal
Cinco Saltos
Cipolletti
General Roca
Villa Regina
Choele Choel
Río Colorado
La Adela
0
50
100 km


A
B
Probability of Aedes aegypti presence
1.00
0.75
0.50
0.25
0.00
-1
0
1
Annual accumulated precipitation (mm)
Minimum temperature (°C)



1800
1600
1400
1200
1000
800
600
400
Accumulated precipitation (mm)
23
24
25
26
Maximum temperature (°C)
1.0
0.8
0.6
0.4
0.2
0.0

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: